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Patent Application Transmittal Letter

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Sir:

Transmitted herewith for filing under 37 CFR 1.53(b) is a(n): ☒ Utility ☐ Design☒ original patent application,☐ continuing application,☐ continuation-in-part☐ continuation or ☐ divisionalof S/N none filed none

INVENTOR(S): David H. Donovan, Miquel Boleda, Johan Lammens and
Francesc Subirada

TITLE: "APPARATUS AND METHOD FOR MITIGATING
COLORANT-DEPOSITION ERRORS IN INCREMENTAL PRINTING"

Enclosed are:

- ☒ The Declaration and Power of Attorney. ☐ signed ☒ unsigned or partially signed
☒ 6 sheets of ☐ formal drawings ☒ informal drawings (one set)
☐ Information Disclosure Statement and Form PTO-1449 ☐ Associate Power of Attorney
☐ Priority document(s) ☒ 2 ACKNOWLEDGEMENT CARDS
☐ (Other) FOR DATE STAMPING & RETURN (fee \$)

CLAIMS AS FILED BY OTHER THAN A SMALL ENTITY				
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1 ble; and some density-related aspects of the invention
2 would be applicable even in far more remote grid forms,
3 e. g. polar. The invention employs diverse techniques, in
4 some cases particularly exploiting crossover effects be-
5 tween coloration phenomena and dimensional phenomena, to
6 mitigate colorant-deposition error ("CDE") and thereby op-
7 timize image quality.

11 BACKGROUND OF THE INVENTION

13 Incremental printing is based on accurate deposition
14 of small colorant dots onto specified locations on paper
15 or other printing media. In inkjet printing such place-
16 ment takes the form of ballistic delivery of ink droplets.

17 Typically these mechanisms form a rectangular grid
18 of specified resolution, the most common resolutions now
19 being twelve by twelve, or twenty-four by twenty-four,
20 dots per millimeter (three hundred by three hundred or six
21 hundred by six hundred dots per inch). Other formats,
22 however, are continuously evaluated.

23 At least two important mechanisms give rise to in-
24 tractable difficulties in the control of CDE. As to the
25 types of CDE associated with dot-density variations, such
26 stringent difficulties occur even in monochrome printing.

27 As to the types of CDE associated with optimum print-
28 medium-advance variations, such difficulties generally
29 exceed available correction resources in printing that
30 combines different color planes, most-commonly primary
31 colors but also other color sets such as hexachrome or
32 light colors form the images. In this case the major
33 difficulty arises directly from the basic requirement for

1 interrelated delivery of different colorants into common
2 areas.

3 4 5 1. ERROR TYPES 6

7 For purposes of this document, CDE encompasses at
8 least four main types of directly observable error — each
9 of which can occur alone under some conditions, although
10 these types are generally interrelated in complex ways:
11

- 12 (1) individual-element density error,
- 13
- 14 (2) swath-height error ("SWE"),
- 15
- 16 (3) area-fill nonuniformity ("AFNU"), and
- 17
- 18 (4) ink-media interactions.
- 19

20 The first of these refers to individual printing ele-
21 ments — whether or not correctly aimed — whose printed
22 dots are either too dark or too light. In inkjet printing
23 such error can be due to variation in drop weight, drop
24 shape or other effects.

25 The second, SWE, refers to swaths that appear too
26 tall or too shallow, most commonly regarded as due to aim-
27 ing errors near the ends of the array. Some SWE effects,
28 however, can result from density errors in those regions.
29 (The acronym "SWE" derives from earlier popular nomencla-
30 ture, "swath width error".)

31 The third type of error, AFNU, refers to nonuniform
32 density in an image field that is printed in response to
33 uniform image-data. This kind of error can result from
34 either of the first two errors — or from aiming error not

1 particularly concentrated at the array ends, or from an
2 undefined complex of dot-placement attributes.

3 Such placement attributes most likely implicate in-
4 teractions between colorant and a printing medium on which
5 the colorant is deposited. This is the fourth category of
6 error effects — "ink-media interactions".

7 {The terminology AFNU, here "area fill nonuniformi-
8 ty", is used in some industrial facilities to connote a
9 more-specific type of defect — a blotchy or mottled ap-
10 pearance. The present inventors wish to point this out
11 simply to avoid confusion due to these slightly different
12 usages. AFNU as used in this document may be regarded as
13 meaning in essence "swath fill nonuniformity".)

14 The effects and causes discussed above are not rela-
15 ted to each other in rigorously the cause-and-effect ways
16 suggested. Thus for example a cause of the third type of
17 error, nonuniform density, can be ink-media interactions;
18 and such interactions, for some purposes, accordingly
19 might be better listed as a cause, rather than an effect.
20 As will be seen shortly, precise categorization of these
21 relationships is not significant to either understanding
22 or validity of the present invention.

23 While AFNU and SWE may present themselves to a viewer
24 as distinct matters of spatial distribution and spatial
25 deformation respectively, in actuality what appears to be
26 a deformation of swath height (or any other shape) can be
27 caused by perturbed colorant distribution. In other words
28 deformation is nested within distribution error.

31 2. SHORTENED LIFE OF PRINTING ARRAYS

33 Currently multielement printing arrays (including for
34 example "printheads" or multinozzle "pens" in inkjet

1 lation that has only, say, a number of rows that equals
2 the number of printheads — and two columns (one for ef-
3 fective swath height and the other for current-swath ink
4 usage) — plus the weighted mean.

5 The number of printheads and therefore rows in the
6 equivalent tabulation is nowadays most typically four,
7 though systems with six or seven printheads are becoming
8 common. In any event the size of the equivalent tabula-
9 tion, at least currently, is less than ten by two, plus
10 the resultant weighted swath-height value (again, just one
11 single number).

12 In the course of calibration, and preparation for op-
13 eration, the system in effect modifies a tabulation of
14 this general size. The rough size of this tabulation or
15 data array may be borne in mind for comparison with later
16 discussions of the invention.

17 18 19 4. AUTOMATIC SUBSTITUTIONS AND WEIGHTING

20
21 As to density error, a current tactic substitutes
22 healthy printing elements for defective ones — either
23 directly or on a statistical, weighting basis — as is
24 taught, for instance, in the above-mentioned earlier pat-
25 ent documents of Garcia-Reyero. This approach, however,
26 has its own distinct limitations.

27 It requires use of multipass printmodes, which is
28 relatively slow. If many elements behave poorly, this ap-
29 proach may not work or may require switching to an even
30 slower printmode.

31 The weighting versions of this technique are more
32 broadly applicable, for they allow defective nozzles to be
33 used less than healthy ones — rather than not at all —
34 and thereby tend to make whatever use can be made of each

1 nozzle. As a practical matter weighting appears to be
2 more useful in cases of misdirected elements than weak or
3 overstrong elements.

4 Density errors due to elements that form too-dark or
5 too-light marks are not corrected adequately by any prior
6 technique — particularly not any that is usable with a
7 small number of passes, e. g. one- or two-pass printmodes.
8 The same is true of ink-media interactions; and the fore-
9 going discussions also cover AFNU, whether associated with
10 SWE or density phenomena.

11
12 As is well known, an incremental printing system
13 establishes average density levels through processes
14 called "rendition", which most typically take the form of
15 either dithering or error diffusion. Dithering employs a
16 relatively large dither mask or rendition matrix — a much
17 larger numerical data tabulation than the effective tabu-
18 lation discussed above as to SWE management.

19 The dither mask is substantially greater, ordinarily,
20 than a ten-row-by-ten-column table; however, it is set at
21 the factory and ordinarily undergoes no modification in
22 the field. This too may be borne in mind for comparison
23 with later discussion of the invention.

24

25

26

27 5. COST

28

29 Furthermore, these several limitations of corrective
30 techniques known heretofore are present even though multi-
31 element printing arrays are subject to relatively strin-
32 gent manufacturing tolerances and therefore relatively
33 expensive. Manufacture and use of printing arrays (inkjet
34 pens etc.) could be considerably more economical if the

1 printing apparatus and methods were significantly more
2 tolerant of both aiming and density errors, as well as
3 ink-media artifacts.

4
5
6 6. CONCLUSION

7
8 Inadequate management of the four main error types
9 introduced above has continued to impede achievement of
10 uniformly excellent incremental printing — at high
11 throughput — on all industrially important printing
12 media. Thus important aspects of the technology used in
13 the field of the invention remain amenable to useful
14 refinement.

15
16
17
18 SUMMARY OF THE DISCLOSURE

19
20 The present invention introduces such refinement. In
21 its preferred embodiments, the present invention has
22 several aspects or facets that can be used independently,
23 although they are preferably employed together to optimize
24 their benefits.

25
26 In preferred embodiments of a first of its facets or
27 aspects, the invention is apparatus for printing desired
28 images on a printing medium, based upon input image data.
29 The apparatus prints images by construction from individu-
30 al marks formed in a pixel grid.

31 The apparatus includes at least one multielement in-
32 cremental-printing array that is subject to colorant-depo-
33 sition error ("CDE"). The apparatus includes some means
34 for measuring such colorant-deposition error of the at

1 include a halftoning matrix; and that the spatial-resolu-
 2 tion relationship include a scaling of the image data to
 3 the pixel grid. It may now be seen that "modifying a mul-
 4 ticolumn, multirow numerical tabulation" encompasses mod-
 5 ification of either a relatively large dither mask (not
 6 heretofore modified by the apparatus in the field) or the
 7 even much larger image-data tabulation itself (not hereto-
 8 fore modified to correct swath-height error).

9
 10 Another basic preference is that the "at least one"
 11 multielement incremental-printing array in fact include a
 12 plurality of multielement printing arrays that print in a
 13 corresponding plurality of different colors or color dilu-
 14 tions. Each multielement printing array is subject to a
 15 respective colorant-deposition error.

16 The measuring means and the modifying means each op-
 17 erate with respect to each one of the plurality of multi-
 18 element printing arrays respectively. (In this case, once
 19 again no actual correction need be made to satisfy this
 20 definition, when operation of the measuring means finds no
 21 error.)

22 A further preference applies to such a multielement
 23 embodiment when the colorant-deposition error includes a
 24 respective pattern of printing-density defects for at
 25 least one of the plurality of multielement printing ar-
 26 rays. Here the measuring means measure the pattern of
 27 printing-density defects for each multielement printing
 28 array respectively. Correspondingly the modifying means
 29 apply the respective pattern of density defects, for at
 30 least one of the multielement printing arrays, to modify a
 31 respective one of said mappings.

32 An analogous preference applies to a multielement em-
 33 bodiment, when the colorant-deposition error includes a
 34 respective swath-height error, for at least one array. In

1 particular element of the multielement printing array,
2 respectively.

3 The procedure builds an identity map of the multiele-
4 ment printing array, through the printmask, into the half-
5 tone thresholding process, thus customizing the threshold-
6 ing process for each pass. Except in the case of randomly
7 varying printmasks, usually masks are reused many times in
8 a known sequence; therefore the customized matrices are
9 reusable many times down the page, though not usually in
10 immediately succeeding passes.

11
12 Another preference applies when the "at least one"
13 multielement incremental-printing array actually is a plu-
14 rality of multielement printing arrays that print in a
15 corresponding plurality of different colors or color dilu-
16 tions. In such cases each multielement printing array is
17 commonly subject to a respective pattern of printing-
18 density defects; and preferably the measuring, deriving,
19 applying and printing steps of the invention are each
20 performed with respect to each multielement printing array
21 respectively.

22 In such cases, in transverse-scanning systems of the
23 sort mentioned earlier it is common for each array also to
24 be subject to a respective swath-height error. In this
25 situation the measuring, deriving, applying and printing
26 steps are also used to modify swath height of each multi-
27 element printing array, for accommodating the swath-height
28 error of each multielement printing array respectively.

29 Twin preferences as to the character of the halftone
30 thresholding process are that it include definition of
31 either a halftone matrix or an error-diffusion protocol.
32 In the latter case, that protocol includes either a pro-
33 gressive error-distribution allocation protocol of the
34 error-diffusion halftoning, or a decisional protocol for

1 determining whether to mark a particular pixel — or pref-
2 erably both.

3 As to the character of the applying step, there are
4 three selectable options for use in that step. It may in-
5 clude replacing values above or below a threshold value,
6 or multiplying values by a linear factor, or applying a
7 gamma correction function to values — or combinations of
8 any two or more of these options.

9 The best single option is the gamma function. While
10 the others are useable, a gamma function is best because
11 it can be made linear in perceptual terms with the visual
12 response of the eye.

13 Therefore with a gamma function the invention can
14 avoid overcorrecting — e. g., converting an objectionable
15 dark line to an objectionable light line — or undercor-
16 recting. Thereby the operation of the invention can be
17 better matched to a variety of image densities.

18 Yet another preference is that the printing stage
19 include single-pass printing. In most but not all such
20 cases the earlier-discussed intermediate mapping stage
21 vanishes, as typically the halftoning matrix is maintained
22 in step with a multielement printing array throughout an
23 entire image.

24 In an event it is particularly preferable to select
25 some operating strategy that maintains a one-to-one map-
26 ping between the halftone thresholding process and each of
27 the printing arrays. This enables a preferable simplified
28 form of the invention — namely, that for each of the plu-
29 rality of multielement arrays, the measuring, deriving and
30 applying steps are each performed at most only one time
31 for a full image.

32
33

1 In preferred embodiments of a third basic facet or
2 aspect, the invention is again a method of printing a
3 desired image, based on input image data. The printing
4 occurs by construction from individual marks formed in a
5 pixel grid by at least one scanning multielement printing
6 array.

7 The printing is subject to print-quality defects due
8 to departure of printing-medium advance from an optimum
9 value. These defects commonly take the form of swath-
10 height error (SWE), but can instead appear as area-fill
11 nonuniformity (AFNU) — both introduced earlier. Either
12 of these forms, as also noted above, can in turn be due to
13 print-element aiming errors, or to ink-media interactions
14 or other colorant-deposition attributes (whether or not
15 known), or even to simple density errors.

16 The method includes the steps of measuring a param-
17 ter related to such print-quality defects, and scaling the
18 input image data to compensate for said departure. It
19 also includes the step of printing the image using the
20 scaled input image data.

22 The foregoing may represent a description or defini-
23 tion of the third aspect or facet of the invention in its
24 broadest or most general form. Even as couched in these
25 broad terms, however, it can be seen that this facet of
26 the invention importantly advances the art.

27 In particular, the errors may or may not occur due to
28 aiming or other malfunctions plainly related to any scale
29 of the image data — but may instead be due to inaccurate
30 density or complex matters of ink and media, or may even
31 be wholly unknown. Yet the invention is able to greatly
32 mitigate them by adjusting the scale of the data.

33 Thus the invention recognizes and exploits crossover
34 effects between dimensional and coloration phenomena.

1 This observation refers to crossover between (1) dimension-
 2 nal phenomena such as aiming, swath height, and scaling,
 3 on the one hand, and (2) coloration phenomena such as
 4 density, ink-to-media, and other deposition occurrences,
 5 on the other hand.

6
 7 Although the third major aspect of the invention thus
 8 significantly advances the art, nevertheless to optimize
 9 enjoyment of its benefits preferably the invention is
 10 practiced in conjunction with certain additional features
 11 or characteristics. In particular, preferably the meas-
 12 ured parameter includes either the print-quality defects
 13 themselves, or the optimum medium-advance value.

14 Thus if the parameter includes the print-quality
 15 defects, the measuring step includes measuring the print-
 16 quality defects — i. e., measuring swath-height error, or
 17 area-fill nonuniformity. In the latter case of measuring
 18 AFNU, it is preferred to measure the nonuniformity as a
 19 function of advance value.

20 That is to say, the measuring step includes using a
 21 sensing system to measure AFNU for each of plural print-
 22 ing-medium advance values — and then going on to select a
 23 particular advance value that corresponds to minimum non-
 24 uniformity. It will be recalled that the causality which
 25 relates advance value to AFNU may not be entirely known;
 26 yet the method selects an advance value that is best, in-
 27 dependent of causality.

28 An alternative way of describing this dual measure-
 29 ment, but without specific reference to AFNU or any other
 30 individual error type, is simply to say that the parameter
 31 to be measured includes the optimum value. The measuring
 32 step, then, includes determining the optimum value.

33 Another preference is applicable when the "at least
 34 one" scanning multielement printing array includes a plu-

1 BRIEF DESCRIPTION OF THE DRAWINGS

2

3 Fig. 1 is a simplified composite diagram, highly
4 schematic or conceptual, for four companion printheads and
5 showing relationships between nozzle geometries, nozzle
6 drop-ejection profiles, inking-density profiles, and area-
7 fill nonuniformities;

8 Fig. 2 is a like diagram but showing relationships
9 between inverse inking-density profiles (derived from the
10 Fig. 1 density profiles), standard dither matrices and
11 modified dither matrices;

12 Fig. 3 is a like diagram but showing usage of the
13 Fig. 2 modified matrices in printing compensated, uniform
14 area fills using the Fig. 1 nozzles;

15 Fig. 4 is a diagram like Fig. 1 but showing relation-
16 ships between data, nozzle geometries and printed swaths
17 with (in some cases) height errors;

18 Fig. 5 is a like diagram but showing relationships
19 between the Fig. 4 nozzle geometries, data corrected for
20 the Fig. 4 errors, and (in most cases) compensated, prin-
21 ted swaths with proper heights;

22 Fig. 6 is a like diagram but showing data corrected
23 according to a more elaborate protocol and (in all cases)
24 compensated, printed swaths with proper heights;

25 Fig. 7 is a perspective view of the exterior of a
26 printer embodying preferred embodiments of the invention;

27 Fig. 8 is a like view of a scanning carriage and me-
28 dium-advance mechanism in the Fig. 7 printer;

29 Fig. 9 is a highly schematic diagram of the working
30 system of the Fig. 7 and 8 printer, particularly as used
31 to practice preferred embodiments of the above-introduced
32 aspects of the invention;

1 zles, though for the latter these forms of the invention
2 are not the best method.

3 Consider a set of representative printheads or "pens"
4 223-226, assumed to have particular nozzle arrays 23-26
5 respectively for printing in different colors e. g. cyan
6 C, magenta M, yellow Y and black K — each with its own
7 respective specific profile 33-36 of ink ejection, or in
8 other words inking intensity. (For present purposes each
9 nozzle is considered together with its respective firing
10 resistor and all associated effects.)

11 The profile 33 for the cyan pen 223, for example, can
12 be measured by a drop detector when the pen is instructed
13 to eject inkdrops corresponding to e. g. a forty-percent
14 area fill. Ordinarily a simple drop detector measures ink
15 ejection as a function of nozzle number, or location along
16 the nozzle array, without responding to aiming accuracy.

17 Where the nozzles 23 would make a printout that is
18 too dark, the resulting measured drop-detector profile 33
19 may include some regions 33D corresponding to nozzle
20 groups ejecting the equivalent of a fifty-five-percent
21 area fill (note scale markings at top of diagram). Where
22 the printout would be too light, the profile may include
23 other regions 33L corresponding to other nozzle groups
24 that produce flows measuring the equivalent of a twenty-
25 five- or even just ten-percent area fill.

26 Instead of a drop detector, a sensor can be scanned
27 along the advance axis over an actual single-pass printed
28 swath of the commanded area fill, to record the image-
29 density profile 43 in the cyan area fill 53. Unlike a
30 drop detector, a scanned sensor is capable of measuring
31 aiming accuracy as well as tonal level or intensity. For
32 the cyan case assumed here, however, nozzle misdirection
33 is not significant and the density profile 43 accordingly

1 lighten an output printout C' (Fig. 3). It also has re-
2 gions 143D, localized to the light regions 53L of the area
3 fill, that will darken the output printout C'.

4 Thus to the extent that the function 43' can be made
5 an effective inverse of the drop-detector or sensor pro-
6 file 33, 43 for the specific nozzle array 23, the modified
7 matrix 143 substantially eliminates variations introduced
8 by the nozzle-array nonuniformities 33D, 33L and thereby
9 enables the system to produce a substantially uniform area
10 fill C'. The assumed uniformity or regularity of the
11 overall system transfer function has been restored.

12 For example, suppose that a particular nozzle is fir-
13 ing too strongly and thereby producing dots 33D that are
14 too large and thus appear too dark 43D. The overlay of
15 perturbations 143L systematically shifts the average den-
16 sity per unit area to more nearly match that of normally
17 functioning neighboring nozzles.

18 In some printing technologies this can be accom-
19 plished by actually changing the size, darkness or density
20 of individual dots or other marks that are produced by
21 individual nozzles — e. g. by increasing a suitable
22 ejection parameter such as ejection energy or drop volume.
23 In such systems, all the dots printed by a particular
24 overinking nozzle can be adjusted toward lower darkness
25 (i. e. lighter) levels by calling for slightly smaller
26 inkdrops.

27 In thermal-inkjet products of designs currently
28 provided by the Hewlett Packard Company, such individual
29 firing adjustments are not readily accessible (although
30 they are plainly possible in principle), and the technique
31 instead proceeds by reducing the average number of dots
32 printed by each overinking nozzle to compensate for its
33 variant density. What is adjusted is thus the "spatial

1 is usually treated as symmetrical. Sometimes it is sug-
2 gested in such situations to deal with the asymmetry as
3 part of interpen alignment by aligning the centers of the
4 overall extended swaths rather than the centers of the
5 pens.

6 Preferred modified-matrix embodiments of the present
7 invention handle each component of positive SWE indepen-
8 dently without incorporating SWE considerations into the
9 alignment. (In purest principle at least, interpen align-
10 ment can be incorporated into these embodiments of the
11 invention.)

12 The image-density profile 45 is, like the drop-detect-
13 tor profile 35, also a rectangular function -- but like
14 the area-fill swath 55 is too long. The dashed lines
15 45h₁, 45h₂ representing outboard extension of the drop-de-
16 tector profile 35 to the swath 55 may be conceptualized as
17 part of the SWE function 45.

(g) Matrix modification for SWE — It is this composite function whose inverse 45' (Fig. 2) is carried forward 47 into the correction process. The inverse function 45' is thus a swath-height contraction as illustrated. Application of this inverse 45' to the standard dither matrix 48, M(ij) therefore produces a custom matrix 145 in which proportionally length-reduced top and bottom regions 145H₁, 145H₂ are entirely suppressed.

Like the image-lightening regions 143L, 144L discussed above for the cyan and magenta pens, these two end regions 145H₁, 145H₂ — when carried forward 49 to the printing stage (Fig. 3) — suppress printing of the affected portions of the swath. They thus compensate for unwanted dark printing.

33 In this case the "unwanted dark printing" is all of
34 the printing which extends beyond the nominal swath bound-

1 to blend the swaths together in the way suggested for the
2 bottom edge — particularly without producing an undesired
3 darkening within the top edge of the swath, on account of
4 migration and coalescence within as well as just outside
5 the swath.

6 To an extent, such effects may be mitigated by form-
7 ing the surplus inking in bands of different density —
8 e. g. a maximum-density strip 146H₁ immediately inside the
9 top edge and a slightly lighter band 146H₂ just inboard
10 from that high-density band. Even with best techniques,
11 nevertheless, a residual negative SWE effect ΔH (Fig. 3)
12 may persist.

13 In addition, comments analogous to some of those
14 above for positive SWE apply here too. Thus the extra
15 inking that flows outside the physical limit of the nozzle
16 array 26 represent replication or expansion of image de-
17 tail that is just inside that limit — and so represent a
18 deformation of the image.

19
20 (i) Arithmetic of the modification — As indicated
21 earlier, the perturbations of these preferred embodiments
22 are injected into the printing process by modifying a
23 thresholding function — which may e. g. be either a half-
24 tone matrix (dither mask) in dithering, or a structure of
25 threshold values used in error diffusion. By way of re-
26 view, a halftone matrix is a thresholding array used to
27 express multibit color data in binary or plural-bit form,
28 and is typically used to determine dot locations in inkjet
29 and other incremental printing.

30 More specifically, a halftone matrix is used that has
31 the same height (expressed as a number of rows) as the
32 printing-element array or printhead (e. g. pen) has ele-
33 ments (e. g. nozzles) — or, if halftoning at lower reso-

1 reasons (such as memory efficiency) advantageously the
2 value is simply clipped to 255.

3 Since source image data generally is eight-bit (val-
4 ues of zero through 255), in many systems a thresholding
5 value greater than 255 will not behave differently than a
6 value of 255. Thus in such systems there is no practical
7 difference between clipping to 255 and leaving the value
8 unedited. (The contrary is the case, however, in systems
9 that treat values above 255 merely by suppressing a fur-
10 ther binary place — i. e. a most-significant ninth bit.)

11 To create an adjusted halftone, a(j) and b(j) values
12 are specified for each row of the halftone matrix. Usu-
13 ally the same b value can be used for all rows, and the a
14 value corresponds to an amount by which each row should be
15 changed.

16 For automatic operation in the field, the a values
17 may be set in response to measured deviation of ink level
18 at the position of each printing element or group, e. g.

19
$$a(j) = \frac{\text{measured tonal value}}{\text{commanded tonal value}} .$$

20

21 Each cell of the halftone is recalculated using the corre-
22 sponding a and b values for that row of the halftone.

23 The other above-mentioned methods are less desirable.
24 A linear correction, in particular, tends to overcorrect
25 in light image areas; while a thresholding model corrects
26 only very dark image areas, and rather imprecisely — but
27 can be useful for swath-bleed situations. With the gui-
28 dance of these stated relationships, combinations of the
29 formulas introduced above — or other correction formulas
30 — can be used instead.

31 In any event the resulting halftone matrix M' is ad-
32 vantageously used to halftone image data, introducing the
33 pattern of density corrections into the printing pipeline.

1 The equalizing effects flow through to the end and occur
2 in the resulting printed image.

3 The halftoning should begin with the top row of the
4 image being halftoned, and with the matrix row correspond-
5 ing to the nozzle that will be used to start printing.
6 Usually these are rows "1" and "1", respectively, in a
7 single-pass printmode.

8
9 (k) Multipass printmodes — For multipass printmodes,
10 the halftone matrix is further constrained to be an inte-
11 gral multiple of the width of the printmask. (This condi-
12 tion is counter to some antipatterning principles taught
13 in the previously mentioned Borrell document; in event ob-
14 jectionable pattern effects arise, an accommodation with
15 those principles should be considered.)

16 In this case an additional matrix $N(ij)$ should be
17 constructed, containing values representing the nozzle
18 that will be used to print each cell of the halftone. De-
19 pending on the complexity of the printmode, this additio-
20 nal mapping matrix can be created either manually or by
21 straightforward calculations; it is used as follows.

22
23 Threshold method:

24 if $M(ij)$ is greater (less) than threshold $t(N(ij))$,
25 then $M'(ij) = 0$ (or other specific value);
26 otherwise $M'(ij) = M(ij)$

27
28 Linear correction:

29 $M'(ij) = a(N(ij)) \cdot M(ij)$

30
31 Gamma correction (assuming a matrix normalized to one):

32 $M'(ij) = M(ij) + a(N(ij)) \cdot M(ij)^{b(N(ij))}$

1 As before, halftoning should begin with the top row
2 of the image being halftoned, and with the matrix row cor-
3 responding to the nozzle that will be used to start print-
4 ing. Now, however, the latter matrix row is likely to be
5 some row other than "1". Printing techniques that use un-
6 usual advances in certain regions of a page, e. g. at top
7 and bottom, may not work optimally with these embodiments
8 of the invention — at least within those page regions.

9
10 As noted earlier, these embodiments are not limited
11 to the kind of rendition known as dithering, but rather
12 can be applied to other rendition types as well — partic-
13 ularly to error diffusion. For example, the $N(ij)$ matrix
14 is advantageously used to perturb the threshold decision
15 whether to print a dot in a particular pixel — or how
16 much error to pass along to other cells, or both.

17
18 These embodiments can compensate for some interswath
19 density variations even when due to aiming errors at ends
20 of the printhead, i. e. true swath-height error. Positive
21 swath-height error, which is to say overlong swath dimen-
22 sion along the advance axis leading to swath overlap, can
23 be actually eliminated by lowering the firing intensity of
24 end elements — i. e. turning them down or entirely off.

25 Even a slight negative swath-height error can be sub-
26 stantially corrected by raising the intensity of those end
27 elements to provide extra inking at the ends of the array.
28 Although the directionality error may remain, its effects
29 can be masked — either by some ink migration on the page
30 after deposition, or by an optical illusion which visually
31 blends a white streak with an immediately adjacent dark
32 line formed by extra inking.

(1) Some benefits — Compared with other techniques, these embodiments of the invention are more effective in managing very large numbers of weak (or dark) nozzles. These embodiments also work well in printmodes with one pass or a small number of passes, for which other techniques work poorly or not at all.

In addition these embodiments are computationally quick. For each print the perturbed halftone matrix need be calculated only once, a fairly minor task, and all the correction work is thereafter free — done in the process of halftoning. This characteristic makes these embodiments of the invention particularly powerful for printers with limited computational power or memory.

2. SIMPLIFIED NUMERICAL EXAMPLES

Assume first a system that has a six-nozzle printhead and uses a dither mask (halftone matrix) which is six rows tall and six columns wide. This mask is used to determine where to print each dot, based on input Contone image data having values of zero through 255 at each pixel:

	column	column	column	column	column	column
	1	2	3	4	5	6
row1	1	161	81	17	188	204
row2	65	225	209	129	60	124
row3	177	33	241	97	8	168
row4	49	113	145	193	72	14
row5	232	174	94	30	184	200
row6	78	238	222	142	56	120

As is conventional, the matrix is tiled across the entire image. A dot is printed at each location where the Contone data value exceeds the halftone cell value.

1 (a) Weak nozzles — Now assume that nozzles number 3
2 and 4 print twenty-percent lighter than their neighbors —
3 i. e., that rows 3 and 4 in each six-row sequence on a
4 page are lighter than the other four rows. The invention
5 can therefore modify these rows by using the correction
6 formula to adjust the average darkness of printing by
7 nozzles number 3 and 4.

8 A suitable implementation for this example uses row
9 correction-factor and overall gamma values of $\underline{a} = -0.2$ and
10 $\underline{b} = 2.2$; the negative sign for \underline{a} may be understood as a
11 designation that the row is light, or weak. These set-
12 tings cause the numbers in the dither mask, for the weak
13 nozzles, to be lower — so that the threshold condition
14 for printing is more easily satisfied.

15 Therefore the third and fourth nozzles print more
16 frequently, raising the density of the corresponding two
17 rows. Inserting these correction-factor and gamma values
18 into the formula introduced earlier, the new values for
19 these two rows will follow the rule:

$$\begin{aligned} 20 \quad \underline{M'}(\underline{ij}) &= \underline{M}(\underline{ij}) + \underline{a}(\underline{N}(\underline{ij})) \cdot \underline{M}(\underline{ij})^{\underline{b}(\underline{N}(\underline{ij}))} \\ 21 &= \underline{M}(\underline{ij}) - 0.2 \cdot \underline{M}(\underline{ij})^{2.2}. \end{aligned}$$

22 As will be recalled, the values must be suitably pre-
23 normalized and renormalized to the 255-value scale; this
24 is not explicitly shown here. It may be seen, however, in
25 the results.

		b,		column	column	column	column	column	column
		a	gamma	1	2	3	4	5	6
27	row1	0	2.2	1	161	81	17	188	204
28	row2	0	2.2	65	225	209	129	60	124
29	row3	-0.2	2.2	154	32	196	90	7	147
30	row4	-0.2	2.2	47	104	130	165	68	13
31	row5	0	2.2	232	174	94	30	184	200
32	row6	0	2.2	78	238	222	142	56	120

33
34 By virtue of the negative sign of $\underline{a} = -0.2$, rows 3
35 and 4 now contain smaller values than before, so that, as

explained above, after these numbers are applied in the thresholding process more dots will be printed for like density. Furthermore, by virtue of the elevated value of gamma or $\underline{b} \gg 1$, large values have changed more than small ones have — which implies that greater adjustment will occur in darker image regions. This effect is desirable because light-printed rows are more noticeable in darker regions.

(b) Interswath bleed — For another example, assume that a printhead is producing bleed between swaths. Such a defect causes darker appearance in the printout at the swath edges.

The invention can resolve this by modifying rows number 1 and 6 to reduce the amount of ink printed at the swath edges. In this case preferably the correction factor $\underline{a} = +0.5$ (the positive sign corresponding to over-strong or dark nozzles), and gamma $\underline{b} = 4$, so that the formula appears thus:

$$M'(ij) = M(ij) + 0.5 \cdot M(ij)^4,$$

and the first and sixth rows of the modified matrix now contain larger values than before —

		b,	column	column	column	column	column	column	
		a	gamma	1	2	3	4	5	6
row1	+0.5	4		1	181	82	17	225	255
row2	0	4		65	225	209	129	60	124
row3	0	4		177	33	241	97	8	168
row4	0	4		49	113	145	193	72	14
row5	0	4		232	174	94	30	184	200
row6	+0.5	4		79	333	294	154	56	126

so that fewer dots are printed in the corresponding rows of the image. This should compensate for the darker appearance at swath boundaries.

Again, using a large gamma — well over unity — provides a larger correction in dark areas, where this prob-

1 lem too is more noticeable. In practice, values larger
2 than 255 in most systems are best clipped to 255.

3. "SWE" CORRECTION BY DATA SCALING

6 (a) The SWE problem and data scaling — In the prior
7 art, a color plane corresponding to a printhead with nomi-
8 nal swath height \underline{H} and actual swath height $\underline{H} + \underline{h}$ must be
9 printed with an overadvance (if SWE is positive) equal to
10 the error \underline{h} in each pass. Avoiding all the adverse conse-
11 quences of such overadvance is a major objective of pre-
12 ferred data-scaling embodiments of the invention.

13 The image data 134 (Fig. 4) for such a color plane
14 can instead be scaled down by the factor $\underline{H}/(\underline{h} + \underline{H})$. This
15 adjustment affects the height of each individual swath so
16 that in theory the influence of the error \underline{h} cancels out:

$$17 \quad (\underline{H} + \underline{h}) \cdot \frac{\underline{H}}{\underline{H} + \underline{h}} = \underline{H}.$$

18 To see how this technique works, it is necessary to
19 consider an element not shown expressly in Figs. 1 through
20 3, namely the input data 133-136 (Fig. 4). Another fea-
21 ture of specific interest — particularly in compensating
22 for negative SWE, as will be seen — is the reservation of
23 nozzles 123R-126R at the ends of the array for use in in-
24 terpen alignment.

25 (Note that the printheads and their nozzle arrays are
26 shown at various heights relative to one another, and rel-
27 ative to the nominal swath limits 137. Thus the nozzles
28 that are marked 123R-126R in the drawing are those which
29 remain reserved after the alignment process has selected
30 only some of all the initially reserved nozzles for use in
31 printing.)

1 For a particular nozzle array 123 that has zero SWE
2 (dashed lines 153H are horizontal), a swath-data array 133
3 with nominal swath boundaries 137 results in a printed
4 swath 153 — printed in cyan, C, for the illustrated exam-
5 ple. This swath 153 is likewise aligned to the same nomi-
6 nal boundaries 137.

7 In the prior art, no printing-medium overadvance is
8 needed for such an ideal case — and in the simplest of
9 the preferred data-scaling embodiments (Fig. 5) of the
10 present invention, no scaling of the input data 133' is
11 needed, either — to obtain a well-aligned cyan printout
12 C'. (Unlike the cases considered in Figs. 1 through 3,
13 the data content here is immaterial, and accordingly no
14 internal structure is illustrated for the printout 153.)
15

16 (b) Correcting positive SWE — For a particular noz-
17 zle array 124 that has a positive swath-height error ef-
18 fect 154H (Fig. 4), however, a swath-data array 134 with
19 the same nominal swath boundaries 137 instead expands into
20 an overlong swath 154. To cure this error the input data
21 134 are scaled down, in inverse proportion to the expan-
22 sion 154H, to form a shallower data array 134' (Fig. 5).

23 This technique, unlike the modified-matrix embodiment
24 discussed earlier, requires no formation of any inverse
25 function. Rather, the expanding pattern 154H is permitted
26 to persist — but based upon a smaller starting base in
27 the contracted data 134'. Some related teachings appear
28 in the previously mentioned documents of Askeland.

29 In printing now, to a first approximation a propor-
30 tional expansion 154H' should provide a new, likewise
31 shallower swath printout 154' — in magenta, M, for the
32 illustrated example — that is fitted to the nominal swath
33 boundaries 137. What makes this only a first approxima-
34 tion, once again, is nonlinearity of the PAD error, i. e.

second-order effects: it may be only the nozzles at the extreme ends of the nozzle array 124 that are particularly responsible for the bulk of the PAD error and therefore the SWE 154H — but the shallower data array 134' never invokes these nozzles.

Nevertheless, with iteration as indicated earlier for the modified-matrix embodiments the data-scaling embodiments too can ordinarily find the optimum data scaling for a precise fit of the positive-SWE nozzle output to the nominal swath boundaries 137. This solution discards no part of the image; however, some inherent internal image deformation arises from the concentration of PAD error in particular regions of the nozzle array, and the present method makes no effort to correct this extremely small deformation.

Some lowering of tonal level may be seen in the end regions of the printed swath as suggested earlier, perhaps due to diverging inkdrop paths there. Such effects can be corrected by simultaneous application of the modified-matrix embodiments of the invention, to adjust the level while data scaling is used to adjust the swath height.

(c) Correcting moderate negative SWE — As in the earlier modified-matrix discussion, it is helpful to consider two distinct subcases of negative error, i. e. error $\underline{h} < 0$. The first of these subcases involves error whose absolute value is relatively small.

The error h due to PAD error in the particular nozzle array 125 can be seen as a contracting pattern 155H (Fig. 4), yielding a slightly shallow swath 155 — to be printed in yellow, Y, for the illustrated example. Consequently, to compensate, the data scaling expands the corresponding data swath 135, providing a slightly taller scaled data array 135' (Fig. 5).

1 Now with a contraction 155H' proportional to the
2 original contraction 155H, the printed swath 155' precise-
3 ly matches the nominal swath boundaries 137. This is ta-
4 ken to be physically possible because there are physical
5 nozzles available above and below the nominal boundaries
6 137 to print the data in those positions.

7 Those nozzles are some of the nozzles 125R nominally
8 reserved for alignment, as mentioned earlier. Fig. 5
9 shows this condition for the scaled yellow array 135',
10 nozzle array 125, and the resulting neatly aligned yellow
11 swath 155'.

12 Because of the varying mechanical alignment of the
13 printheads (as distinguished from their nozzle arrays),
14 the numbers of nozzles 125R remaining reserved after soft-
15 ware alignment — as marked in the drawings — in general
16 are different at top and bottom of each array, as well as
17 from pen to pen. For the particular example illustrated
18 as array 125, this fact does not come into play — since
19 ample reserved nozzles 125R are shown as remaining avail-
20 able at both ends.

21 For this first subcase 135', of moderate negative
22 swath-height error, as seen it is possible to achieve a
23 nominal swath height — just matching that of the zero-
24 error and positive-error cases 133', 134'. If all the
25 pens conformed to one or another of these three models,
26 these simple scaling procedures would enable all pens to
27 print compatibly and consistently.

28
29 (d) Correcting severe negative SWE — The second and
30 more-complicated subcase arises for significantly more
31 severe negative SWE 156H (Fig. 4), as seen in the example
32 for the particular black-printing nozzle array 126. In
33 this example the scaled data 136' extend not only well

1 beyond the nominal swath boundaries 137 but also beyond
2 the nozzles 126R remaining available.

3 The example also shows a slightly greater number of
4 nozzles 126R above the upper swath boundary than below the
5 lower swath boundary. In other words, the top 126T of the
6 nozzle array is farther outside the swath than the bottom
7 126B of the array.

8 To obtain symmetrical trimming to both top and bottom
9 boundaries 137, however, the controlling dimension is the
10 shorter distance below the swath to the array bottom 126B.
11 Equidistant above the swath is a symmetrical position
12 126S, which defines the upper usable limit of the array.
13 To maintain the software alignment, the top 126T of the
14 array is thus outside the usable range.

15 The black-marked top and bottom zones 138 of the
16 scaled-up data 136' cannot be printed: no nozzles are
17 physically present for the purpose below the bottom 126B
18 or above the top 126T of the array; and alignment require-
19 ments as just explained prevent use of nozzles in the
20 shallow, slightly lower region between the top 126T and
21 the earlier-mentioned symmetrical limit 126S. (The dark
22 shading 138 here accordingly has a different significance
23 from that at 143D, 144D, 146H in Figs. 2 and 3.)

24 This obstacle arises whenever the scaled data height
25 $\underline{H}^2/(\underline{H} + \underline{h})$ exceeds the height of the maximum usable nozzle
26 complement 156M. The numerical value of the latter 156M
27 cannot be stated in general, since it depends upon the
28 degree of asymmetry and hence upon the severity of me-
29 chanical misalignment between the pens.

30 In cases of extreme mechanical misalignment, all the
31 reserved nozzles at one end of the array or the other are
32 used. In this case the maximum available complement 156M
33 equals the nominal array height H and any negative SWE at

1 all is too much to be resolved by the particular scaling
2 approach of Fig. 5.

3 Redefining, more generally, \underline{m} as the height of the
4 maximum usable nozzle complement (*i. e.* the distance
5 156M), the condition for inadequate available nozzles is:

$$\begin{aligned} \frac{H^2}{H + h} &> \underline{m} \\ h &< H \left(\frac{H}{\underline{m}} - 1 \right) \\ |h| &> H \left(1 - \frac{H}{\underline{m}} \right) \end{aligned}$$

13 Since \underline{m} is always at least as large as \underline{H} , the parenthetical
14 expression in the second line is always zero or negative
15 — and the unavailable-nozzle condition arises for
16 SWE that is negative ($\underline{h} < 0$) and of magnitude large enough
17 to satisfy the condition in the third line.

18 Although the Fig. 5 technique is essentially forbidden
19 in such cases, scaling in general continues to be an
20 attractive option — but requires additional steps. In
21 this case the swath 156 (in the example) of smallest effective
22 height is first identified, and this swath height
23 becomes the controlling dimension for all of the pens.

24 The image data for the pen 126 with this smallest
25 swath height $\underline{H}_{\text{MIN}}$ is scaled to the maximum available nozzle
26 complement \underline{m} for that pen 126. This process yields a
27 scaled data array 136" (Fig. 6), for that pen 126.

28 The pen now necessarily (*i. e.* by definition) has
29 sufficient available nozzles to print. As mentioned
30 above, however, the array 136" may be no taller than the
31 nominal swath height \underline{H} — *i. e.* may just fit the nominal
32 boundaries 137.

33 The negative SWE phenomenon 156H" normally persists,
34 though as before iterative measurement may be needed to

determine its effective value considering the second-order effect described earlier. Given the scaled data 136" and corresponding SWE 156H", a swath 156" can now be printed with new height 156N proportionally shallower than the data 136" and also shallower than the nominal swath height H defined by the nominal boundaries 137.

The height 156N of swath 156" defines a new set of swath boundaries 139 for the system. Other data planes 133, 134, 135 are now rescaled so that their respective SWE effects will all produce printed swaths C", M", Y" precisely fitted to this new system swath height 156N.

This process yields (possibly with iterations as discussed earlier) three more newly scaled data arrays 133", 134" and 135". Depending upon the several factors discussed above, they may be equal to, shallower than or taller than the new system swath height 156N (and the original nominal swath height H) — but all four printed swaths C", M", Y" and K" are of equal height.

The printing-medium advance stroke is adjusted to match this new common swath height 156N. Redefining, more generally, n as the new advance distance and common swath height (i. e. for the example in Fig. 6, the distance 156N), this new system swath height n is set by the parameters of the controlling pen:

$$n = m \frac{H_{min}}{H} = m \frac{H + h}{H}$$

(but preferably making further allowances for necessary iteration).

(e) Review of scaling techniques — Since the scale of each source-image swath is in general changed, not only the individual swath heights but the final overall length, too, of the printout is changed too. Each swath height becomes either the original nominal one H or a new system

standard n — found to a first approximation from the initial height M_{MIN} of the shallowest swath considered together with the available nozzle complement m of the corresponding pen as explained above.

The printed area is filled completely, with neither dark bands nor white streaks. For multiple-color images, in the first analysis the process is applied to each color plane independently and according to the swath-height error of its corresponding printhead only. Through this procedure, however, all of the swath heights are made equal to each other and to the nominal or new system swath height.

Through this technique the residual errors can be as small as the precision in measuring each printhead's swath-height error, for monicolor drawings. In plural-color drawings the errors can be always smaller than a half dot row as will be seen below.

As suggested above, successful practice of these preferred embodiments of the invention requires some measurement to form the basis for the scaling. What is indicated for this purpose, in the above discussion, is direct measurement of swath height and thereby its effective error.

Another valuable feature is the possibility of measuring not the printhead swath-height error but rather only its associated ideal paper-advance stroke that minimizes banding. Such techniques appear in the previously mentioned patent document of Cluet.

Whether these preferred embodiments of the invention are practiced by measuring swath height or ideal advance, in essence the response is the same — namely, using that measured value as the basis for a scaling adjustment as set forth above. In either event the quantity $H + h$ is

1 ensure that scaling is never an expansion — i. e. is al-
2 ways by a factor equal to or less than unity.

3 This condition is ensured by first determining which
4 printhead has the effective (i. e. scaled) swath height
5 H_{MIN} which is shortest (more than one height may be equal
6 to this same value) and then scaling all of the other
7 heads to match that height. Bearing in mind that this
8 overscaling problem occurs only when at least one of the
9 SWE values is negative, $h < 0$, it can be assumed that at
10 least the shortest swath height is $H + h < H$ (the value H
11 as before being the nominal swath height).

12 Next the printing-medium advance stroke is set to
13 underadvance by the amount h of the error for that partic-
14 ular head, the one with shortest effective height. Some-
15 times the entire nozzle complement of that head can be
16 used.

17 The printing-medium advance stroke for all heads is
18 now known — since the system is capable of providing only
19 one single advance distance, common to all heads. Scaling
20 for all the other heads (and their corresponding color
21 planes) must now be a rescaling to that shortest swath-
22 height value H_{MIN} — instead of scaling to their own re-
23 spective nominal heights as before.

24 Now by definition of H_{MIN} each scaling is either an
25 underscaling (scaling by a factor less than unity) or an
26 equality (scaling by a multiple of one). Hence the prob-
27 lem of scaling up into a range of nonexistent nozzles is
28 eliminated.

29 More specifically, depending on the SWE values, each
30 other head will use a number of nozzles equal to or fewer
31 than those of the head with minimum height H_{MIN} . The scale
32 factor for each other color plane and nozzle will be found
33 by calling the function $\text{round}[n \cdot H / (H + h)]$.

As noted earlier, residual error is always smaller than a half dot row, since this is the rounding error that keeps banding defects in an acceptable range for fast, single-pass printouts. This solution optimizes area-fill time, maximizes nozzle usage and maintains maximum accuracy of overall page length.

4. MECHANICAL AND PROGRAM/METHOD FEATURES

The invention is amenable to implementation in a great variety of products. It can be embodied in a printer/plotter that includes a main case 1 (Fig. 7) with a window 2, and a left-hand pod 3 which encloses one end of the chassis. Within that enclosure are carriage-support and -drive mechanics and one end of the printing-medium advance mechanism, as well as a pen-refill station with supplemental ink cartridges.

The printer/plotter also includes a printing-medium roll cover 4, and a receiving bin 5 for lengths or sheets of printing medium on which images have been formed, and which have been ejected from the machine. A bottom brace and storage shelf 6 spans the legs which support the two ends of the case 1.

Just above the print-medium cover 4 is an entry slot 7 for receipt of continuous lengths of printing medium 4. Also included are a lever 8 for control of the gripping of the print medium by the machine.

A front-panel display 211 and controls 212 are mounted in the skin of the right-hand pod 213. That pod encloses the right end of the carriage mechanics and of the medium advance mechanism, and also a printhead cleaning station. Near the bottom of the right-hand pod for readiest access is a standby switch 214.

1 Within the case 1 and pods 3, 213 a cylindrical plat-
2 en 241 (Fig. 9) — driven by a motor 242, worm and worm
3 gear (not shown) under control of signals from a digital
4 electronic processor 71 — rotates to drive sheets or
5 lengths of printing medium 4A in a medium-advance direc-
6 tion. Print medium 4A is thereby drawn out of the print-
7 medium roll cover 4.

8 Meanwhile a pen-holding carriage assembly 220 (Figs.
9 8 and 9) carries several pens 223-226 (Fig. 8) back and
10 forth across the printing medium, along a scanning track
11 — perpendicular to the medium-advance direction — while
12 the pens eject ink. As mentioned earlier, this is one but
13 not the only form of incremental-printing apparatus, an
14 alternative being use of a page-wide pen array with rela-
15 tive motion in relation to the full length of the printing
16 medium. (As will be understood, the term "scan" is also
17 used in describing motion of a measuring sensor over the
18 printing medium, most usually along the medium-advance
19 direction.)

20 For simplicity's sake, only four pens are illustra-
21 ted; however, as is well known a printer may have six pens
22 or more, to hold different colors — or different dilu-
23 tions of the same colors — as in the more-typical four
24 pens. The medium 4A thus receives inkdrops for formation
25 of a desired image, and is ejected into the print-medium
26 bin 5. A colorimetric image sensor 251, quite small,
27 rides on the carriage with the pens.

28
29 A very finely graduated encoder strip 233, 236 (Fig.
30 9) is extended taut along the scanning path of the car-
31 riage assembly 220 and read by another small automatic
32 optoelectronic sensor 237 to provide position and speed
33 information 237B for the microprocessor. One advantageous
34 location for the encoder strip is shown in several of the

1 Before further discussion of details in the block
2 diagrammatic showing of Fig. 9, a general orientation to
3 that drawing may be helpful. Most portions 70, 73-78, 95
4 across the lower half of the diagram, including the print-
5 ing stage 4A-251 at far right, and the pass and nozzle
6 assignments 61, are generally conventional and represent
7 the context of the invention in an inkjet printer/plotter.

8 The top portion 63-72, 81-87 and certain parts 171,
9 172, 89 of the lower portions of the drawing represent the
10 present invention. Given the statements of function and
11 the swath diagrams presented in this document, an experi-
12 enced programmer of ordinary skill in this field can pre-
13 pare suitable programs for operation of all the circuits.

14
15 The pen-carriage assembly is represented separately
16 at 220 when traveling to the left 216 while discharging
17 ink 218, and at 220' when traveling to the right 217 while
18 discharging ink 219. It will be understood that both 220
19 and 220' represent the same pen carriage.

20 The previously mentioned digital processor 71 pro-
21 vides control signals 220B to fire the pens with correct
22 timing, coordinated with platen drive control signals 242A
23 to the platen motor 242, and carriage drive control sig-
24 nals 231A to the carriage drive motor 231. The processor
25 71 develops these carriage drive signals 231A based partly
26 upon information about the carriage speed and position
27 derived from the encoder signals 237B provided by the
28 encoder 237.

29 (In the block diagram almost all illustrated signals
30 are flowing from top toward bottom and left toward right.
31 The exceptions are the information 237B fed back from the
32 codestrip sensor 237, the image-density measurement pro-
33 file data 65 fed back from the colorimetric sensor 251,

1 and the scaling information 172 — all as indicated by the
2 associated leftward arrows.)

3 The codestrip 233, 236 thus enables formation of col-
4 or inkdrops at ultrahigh precision during scanning. This
5 precision is maintained in motion of the carriage assembly
6 220 in each direction — i. e., either left to right (for-
7 ward 220') or right to left (back 220).

8 New image data 70 are received 191 into an image-
9 processing stage 73, which may conventionally include a
10 contrast and color adjustment or correction module 76 and
11 rendition and scaling modules 74, 77, 77'. Most commonly
12 scaling 77 (if any) occurs before rendition 74; however,
13 as shown it is currently known to perform some or all
14 scaling 77' after rendition.

15 A rendition stage 74 typically includes some opera-
16 tional dither matrix 174 or equivalent — e. g. an error-
17 diffusion stage. The operational mask 174 is ordinarily a
18 standard conventional mask, nowadays preferably corrected
19 with a so-called "blue noise" characteristic.

20 According to the present invention, however, the mask
21 is preferably customized according to instructions 68.
22 Analogously the pre- and postrendition scaling modules 77,
23 77' when present typically include standard conventional
24 scaling specifications 173, 173', but in accordance with
25 the invention these values are preferably modified accord-
26 ing to instructions 172, 171.

27
28 Information 195 passing from the image-processing
29 modules next enters a printmasking module 95. This gen-
30 erally includes a stage 61 for specific pass and nozzle
31 assignments. The latter stage 61 performs generally con-
32 ventional functions.

33 Integrated circuits 71 may be distributive — being
34 partly in the printer, partly in an associated computer,

These circuits also may comprise a general-purpose processor (e. g. the central processor of a general-purpose computer) operating software such as may be held for instance in a computer hard drive, or operating firmware (e. g. held in a ROM 75 and for distribution 66 to other components), or both; and may comprise application-specific integrated circuitry. Combinations of these may be used instead.

As set forth above, images to be printed and scanned to establish the modifications prescribed by the present invention may be representative area-fill images of different colors, for reading by the optical sensor 251 to generate calibration data. For generation of such test images, the apparatus of the invention includes — in the integrated-circuit section 71 (Fig. 9) — array-using means 63 that generate control signals 80 for operation of the final output stage 78. These signals drive the printing stage seen at right.

23 Some portions of Fig. 9 correspond to the advance-op-
24 timization functions mentioned earlier. In the case of
25 those optimization embodiments, the array-using means 63
26 include advance-varying means 64 — and in this case the
27 control signals 80 include a series of different paramete-
28 ters for test.

29 Such a series of parameters may for example include a
30 sequence of different printing-medium advance values, as
31 described in detail in the previously identified Cluet
32 document. Each value is duly implemented by the final
33 output stage 78 and its advance-mechanism signals 242A.

These signals 242A are further implemented, in printing of the test images, by the movements of the advance motor 242, drive 241 and medium 4A. The sequence of parameter values is also signaled 91 to color-deposition-error measuring means 72, for use in correlation as also described by Cluet. In the case of the present invention, such correlation yields an advance value that in turn is used in the scaling operations already detailed above.

A small automatic optoelectronic sensor 251 rides with the pens on the carriage and is directed downward to obtain data about image quality — more specifically, uniformity in area fills and swath height, for purposes of the adjustments set forth earlier in this document. The sensor 251 signals are coordinated (not shown) with movements of the carriage and advance mechanism, and thereby can readily perform optical measurements 65, 81, 82 (Fig. 9) of the printed test images. Suitable algorithmic control is well within the skill of the art, guided by the discussions here.

The deposition-error-measuring means 72 receive measurement data 65 returned from the sensor 251. In the case of the optimization embodiments, the CDE-measuring means 72 include means 81 for correlating these quality data 65 with the advance-varying data 91 from the above-mentioned varying means 64.

The correlation data 93, 94 in turn pass to image-optimizing means 89, particularly for control 196 of the printing-medium advance stroke. These data 93, 94 may be used for control 187 of other parameters such as print-mode; print-medium advance speed; scan velocity; inkdrop energies, sizes and velocities; depletion, propletion and discretionary-dotting ratios; balance point between ran-

1 domization vs. granularity; and also nozzle weighting
2 distributions.

3 This correlation function, however — described with
4 greater particularity by Cluet — is here somewhat tangen-
5 tial. For present purposes it simply serves as a way of
6 establishing the previously mentioned ideal swath-height
7 value m employed in the scaling embodiments of the present
8 invention. In any event, the settings in turn pass 187,
9 196 to the final output stage 78 for control of the print-
10 ing stage.

11
12 Other portions of Fig. 9 relate to the mapping modi-
13 fications of the present invention, detailed above. In
14 this case generally there may be no advance-varying means
15 64 or correlating means 89, but there are measurement
16 control signals 80 and resulting measurement data 65.

17 In these embodiments, the measurement data 65 proceed
18 to means 81 or 82 (or both) for respectively quantifying
19 swath-height or density characteristics of the printheads
20 223-226. These two possibilities will now be followed
21 separately.

22 In the relatively simpler case of printing-density
23 defect data 82, as indicated in the earlier detailed dis-
24 cussion such data follow a path 88 to a density-transfor-
25 mation stage 84. In that stage the information is used to
26 form a specifically customized halftoning matrix (or er-
27 ror-diffusion threshold structure) 85, which is then sub-
28 stituted 68 for the standard mask etc. 174 in the rendi-
29 tion stage.

30 In the more-complicated case of swath-height charac-
31 teristic data 81 for use in correction, as indicated in
32 the above detailed discussion such data may follow either
33 (1) a path 92 to the same density-transformation stage 85

1 just discussed, or (2) a path 93 to a spatial-resolution
2 modifying stage 86 — or (3) in some cases both.

3 In the case of the path 93 to the spatial-resolution
4 stage 86, the swath-height characterizing data 81 are ap-
5 plied in forming a modified structure 87 of data scaling.
6 This structure 87 can be applied 172, 171 in lieu of stan-
7 dard scaling 173, 173' in either prerendition or postren-
8 dition scaling 77, 77'.

9
10
11

12 The above disclosure is intended as merely exemplary,
13 and not to limit the scope of the invention — which is to
14 be determined by reference to the appended claims.

WHAT IS CLAIMED IS:

- 1 1. Apparatus for printing a desired image on a printing
2 medium, based upon input image data, by construction from
3 individual marks formed in a pixel grid; said apparatus
4 comprising:
5 at least one multielement incremental-printing array
6 that is subject to colorant-deposition error;
7 means for measuring such colorant-deposition error of
8 the at least one array;
9 means for modifying a multicolumn, multirow numerical
10 tabulation that forms a mapping between such input image
11 data and such marks, to compensate for the measured col-
12 orant-deposition error; and
13 means for printing using the modified mapping.
- 1 2. The apparatus of claim 1, wherein the mapping is
2 selected from the group consisting of:
3 an optical-density transformation of the image data
4 to such construction from individual marks; and
5 a spatial-resolution relationship between the image
6 data and such pixel grid.
- 1 3. The apparatus of claim 2, wherein:
2 the optical-density transformation comprises a half-
3 toning matrix; and
4 the spatial-resolution relationship comprises a scal-
5 ing of the image data to such pixel grid.

1 4. The apparatus of claim 1, wherein:
2 said at least one multielement incremental-printing
3 array comprises a plurality of multielement printing
4 arrays that print in a corresponding plurality of differ-
5 ent colors or color dilutions, each multielement printing
6 array being subject to a respective colorant-deposition
7 error; and
8 the measuring means and the mapping-modifying means
9 each operate with respect to each one of the plurality of
10 multielement printing arrays respectively.

1 5. The apparatus of claim 4, wherein:
2 for at least one of the plurality of multielement
3 printing arrays, the colorant-deposition error comprises a
4 respective pattern of printing-density defects; and where-
5 in:
6 the measuring means comprise means for measuring the
7 pattern of printing-density defects for each multielement
8 printing array respectively; and
9 the modifying means comprising means for applying the
10 respective pattern of defects, for at least one of the
11 multielement printing arrays, to modify a respective said
12 mapping.

1 6. The apparatus of claim 4, wherein:
2 for at least one of the plurality of multielement
3 printing arrays, the colorant-deposition error comprises a
4 swath-height error;
5 the measuring means comprise means for measuring the
6 swath-height error for each multielement printing array
7 respectively; and
8 the modifying means comprise means for applying the
9 respective swath-height error, for at least one of the
10 multielement printing arrays, to modify a respective said
11 mapping.

7. The apparatus of claim 1, wherein:

- the colorant-deposition error comprises a pattern of printing-density defects;
- the measuring means comprise means for measuring the pattern of printing-density defects;
- the modifying means comprise:
 - means for deriving a correction pattern from the measured pattern of printing-density defects, and
 - means for applying the correction pattern to modify a halftone thresholding process; and
- the printing means comprise means for printing such image using the modified halftone thresholding process.

1 8. The apparatus of claim 1, wherein:
2 the colorant-deposition error comprises a swath-
3 height error or otherwise corresponds to a optimum dis-
4 tance of printing-medium advance;
5 the measuring means comprise means for measuring the
6 swath-height error or determining the optimum distance;
7 the modifying means comprise:
8
9 means for deriving a correction pattern from the
10 measured swath-height error or determined
11 optimum distance, and
12
13 means for applying the correction pattern to
14 modify a halftone thresholding process; and
15
16 the printing means comprise means for printing such
17 image using the modified halftone thresholding process.

1 9. A method of printing a desired image, by construction
2 from individual marks formed in a pixel grid by at least
3 one multielement printing array that is subject to a pat-
4 tern of printing-density defects; said method comprising
5 the steps of:
6 measuring such pattern of printing-density defects;
7 deriving a correction pattern from the measured pat-
8 tern of printing-density defects;
9 applying the correction pattern to modify a halftone
10 thresholding process; and
11 printing such image using the modified halftone
12 thresholding process.

1 10. The method of claim 9, for use with a printmask in
2 plural-pass printing, and further comprising the steps of,
3 before or as a part of the applying step:

4 using such printmask to determine a relationship be-
5 tween the halftone matrix and the multielement array; and
6 employing the relationship in the applying step to
7 control application of the correction pattern to the half-
8 tone matrix.

1 11. The method of claim 9, wherein:

2 the printing step comprises single-pass printing.

1 12. The method of claim 9, for use with said at least one
2 multielement incremental-printing array that comprises a
3 plurality of scanning multielement printing arrays that
4 print in a corresponding plurality of different colors or
5 color dilutions, each multielement printing array being
6 subject to a respective swath-height error; and wherein:
7 the measuring, deriving, applying and printing steps
8 are employed to modify swath height of at least one of the
9 scanning multielement printing arrays, for accommodating
10 any swath-height error present in each multielement print-
11 ing array respectively.

1 13. The method of claim 9, for use with said at least one
2 multielement incremental-printing array that comprises a
3 plurality of multielement printing arrays that print in a
4 corresponding plurality of different colors or color dilu-
5 tions, each multielement printing array being subject to a
6 respective pattern of printing-density defects; and where-
7 in:

8 the measuring, deriving, applying and printing steps
9 are each performed with respect to each multielement
10 printing array respectively.

1 14. The method of claim 13, for use with such plurality
2 of multielement incremental-printing arrays that are also
3 each subject to a respective swath-height error; and
4 wherein:

5 the measuring, deriving, applying and printing steps
6 are also employed to modify swath height of at least one
7 of the multielement printing arrays, for accommodating any
8 swath-height error present in each multielement printing
9 array respectively.

1 15. The method of claim 9, wherein:

2 the halftone thresholding process comprises defini-
3 tion of a halftone matrix.

1 16. The method of claim 9, wherein:

2 the halftone thresholding process comprises an error-
3 diffusion protocol.

1 17. The method of claim 16, wherein the error-diffusion
2 protocol comprises at least one of:
3 a progressive error-distribution allocation protocol
4 of such error-diffusion halftoning; and
5 a decisional protocol for determining whether to mark
6 a particular pixel.

1 18. The method of claim 9, wherein:
2 the applying step comprises replacing values above or
3 below a threshold value.

1 19. The method of claim 9, wherein:
2 the applying step comprises multiplying values by a
3 linear factor.

1 20. The method of claim 9, wherein:
2 the applying step comprises applying a gamma cor-
3 rection function to values.

1 21. The method of claim 9, wherein the modifying step
2 comprises a combination of at least two of:
3 replacing values above or below a threshold value;
4 multiplying each values by a linear factor; and
5 applying a gamma correction function to values.

1 22. The method of claim 9, wherein:
2 for each of the plurality of multielement arrays, the
3 measuring, deriving and applying steps are each performed
4 at most only one time for a full image.

1 23. The method of claim 9, wherein:
2 the applying step comprises modifying the darkness of
3 substantially each mark printed by an individual printing
4 element whose density is defective.

1 24. The method of claim 9, wherein:
2 the applying step comprises modifying the average
3 number of dots printed by an individual printing element
4 whose density is defective.

1 25. A method of printing a desired image, based on input
2 image data, by construction from individual marks formed
3 in a pixel grid by at least one scanning multielement
4 printing array; said printing being subject to print-qual-
5 ity defects due to departure of printing-medium advance
6 from an optimum value; said method comprising the steps
7 of:
8 measuring a parameter related to such print-quality
9 defects;
10 based on the measured parameter, scaling such input
11 image data to compensate for said departure; and
12 printing such image using the scaled input image
13 data.

1 26. The method of claim 25, wherein:
2 the parameter comprises such print-quality defects;
3 and
4 the measuring step comprises measuring such print-
5 quality defects.

1 27. The method of claim 26, wherein:
2 the defects comprise swath-height error; and
3 the measuring step comprises measuring swath-height
4 error.

1 28. The method of claim 26, wherein:
2 the defects comprise area-fill nonuniformity; and
3 the measuring step comprises:
4
5 using a sensing system to measure area-fill non-
6 uniformity for plural printing-medium ad-
7 vance values, and
8
9 selecting a printing-medium advance value that
10 corresponds to minimum area-fill non-
11 uniformity.

1 29. The method of claim 25, wherein:
2 the parameter comprises such optimum value; and
3 the measuring step comprises determining such optimum
4 value.

1 30. The method of claim 25, for use with said at least
2 one scanning multielement printing array that comprises a
3 plurality of multielement printing arrays that print in a
4 corresponding plurality of different colors or color dilu-
5 tions, each multielement printing array being subject to a
6 respective swath-height error; wherein:

7 the measuring, scaling and printing steps are each
8 performed with respect to each multielement printing array
9 respectively.

1 31. The method of claim 30, wherein the printing step
2 comprises:

3 comparing optimum advance values or swath-height
4 values measured for the plurality of multielement printing
5 arrays respectively, to find the smallest of said values;

6 selecting a particular multielement printing array
7 whose said value is substantially the smallest;

8 using, in common for the plurality of printing ar-
9 rays, substantially said selected smallest value; and

10 for substantially each array other than the particu-
11 lar array, operating with a respective reduced number of
12 printing elements and with rescaled data, to match an ac-
13 tual effective swath height of the particular array.

1 32. The method of claim 31, wherein:

2 said smallest of said values is determined taking in-
3 to account the maximum available number of printing ele-
4 ments in the corresponding array.

1 33. The method of claim 25, further comprising the step
2 of:
3 after the scaling step, iterating the measuring and
4 scaling steps to allow for nonlinearity in such print-
5 quality defects.

1 APPARATUS AND METHOD FOR MITIGATING
2 COLORANT-DEPOSITION ERRORS IN INCREMENTAL PRINTING

3
4
5 ABSTRACT OF THE DISCLOSURE

6
7 CDE is measured for each nozzle array, to enable mod-
8 ification of a mapping between input image data and inten-
9 ded printing marks to compensate for the CDE. Printing
10 proceeds using the modified mapping, which is either an
11 optical-density transformation of data to printing marks
12 or a spatial-resolution relation between image data and
13 intended pixel grid. The density transformation prefera-
14 bly includes a dither mask (but can be error-diffusion
15 thresholding instead); the resolution relation includes
16 scaling of image data to pixel grid. For some invention
17 forms, CDE includes printing-density defects, measured and
18 used to derive a correction pattern — in turn used to
19 modify halftone thresholding. For other forms CDE in-
20 cludes swath-height error, but still this is measured and
21 used to derive a correction pattern etc. For still other
22 forms, however, CDE includes swath-height error and cor-
23 rection takes the form of scaling. When the halftoning
24 forms are applied to plural-pass printing, a printmask is
25 used to map the dither mask etc. to the nozzle array, en-
26 abling application of the correction to the mask. Half-
27 tone forms ideally uses a gamma function, though threshold
28 or linear corrections are possible instead. Halftone cor-
29 rection is effective in single-pass printing. The swath-
30 height correction can modify heights of all nozzle arrays.
31 Computations are done at most only once for a full image.

Fig. 1

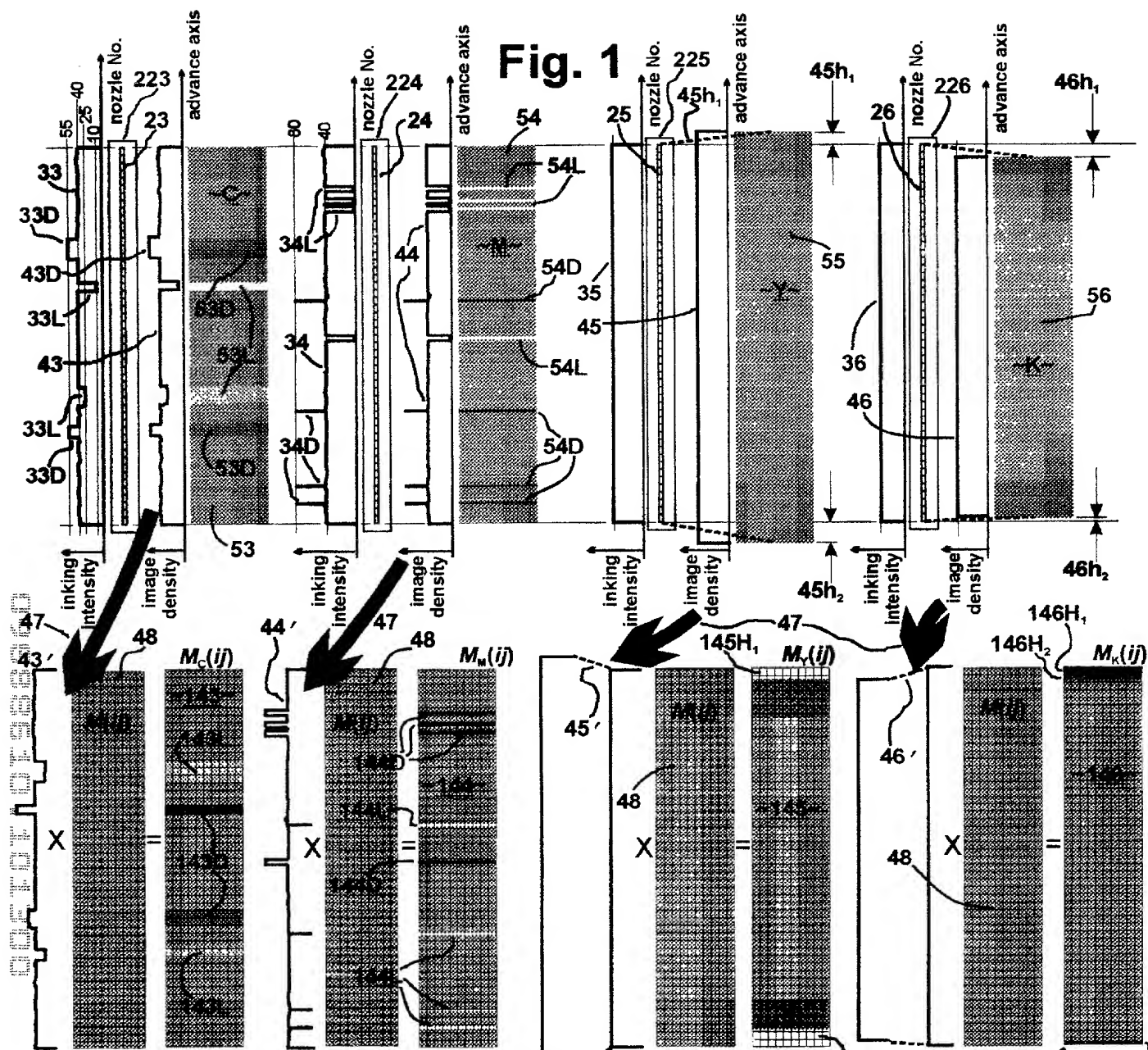


Fig. 2

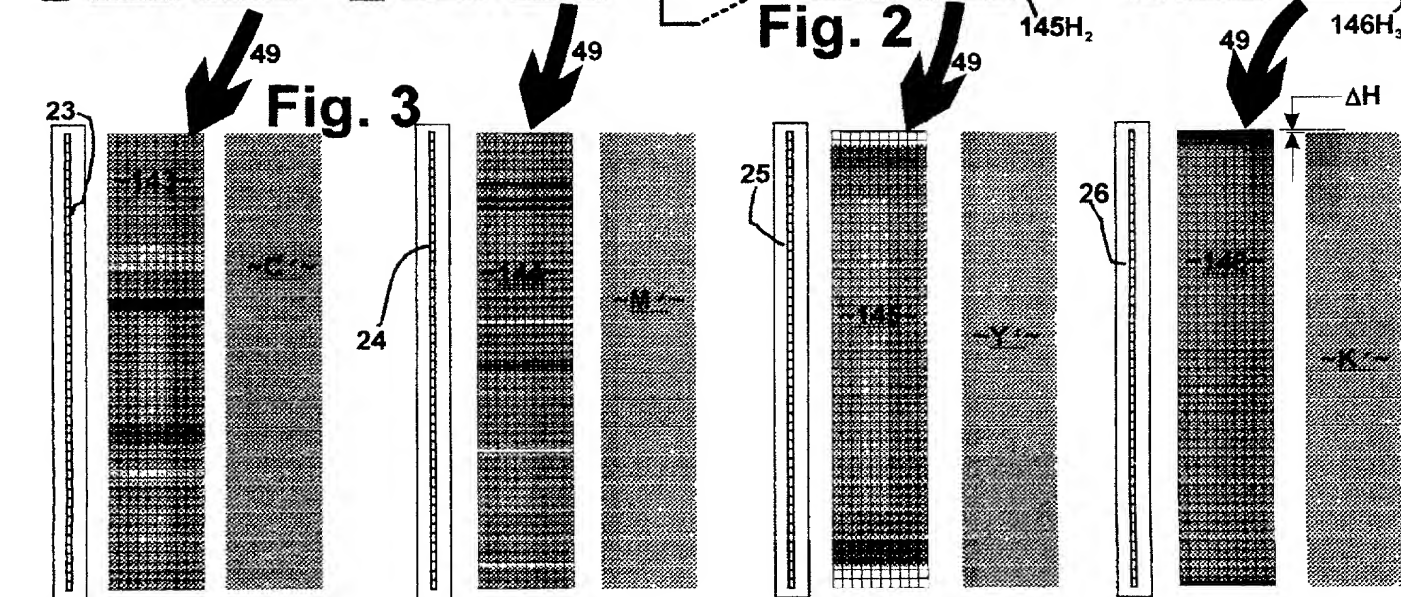


Fig. 3

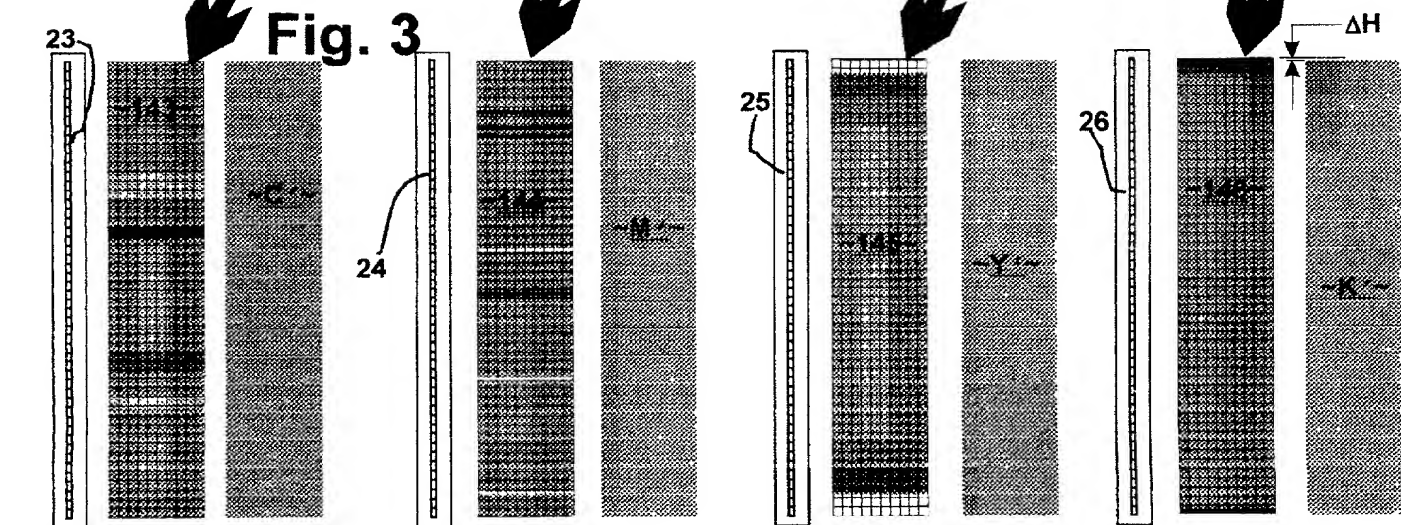


Fig. 4

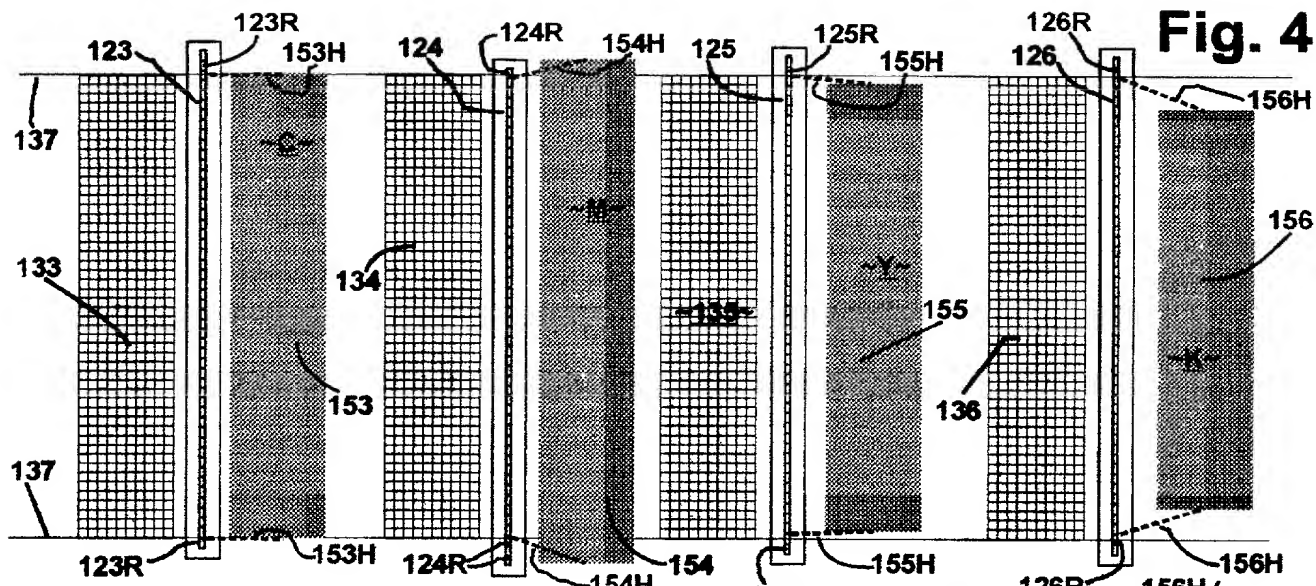


Fig. 5

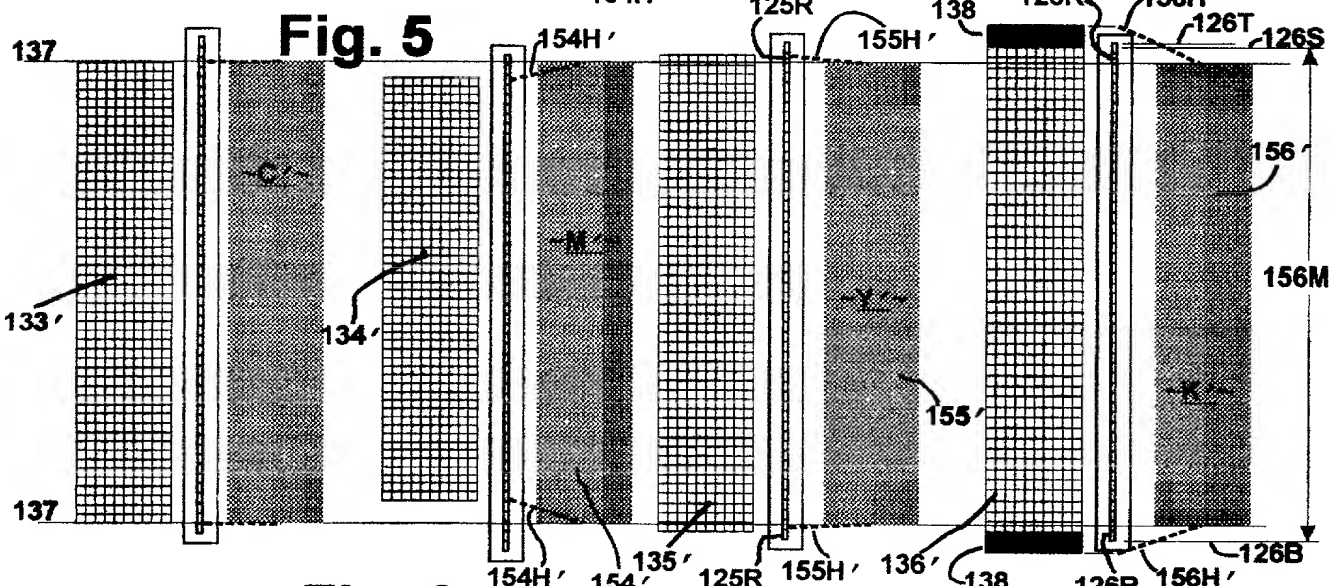
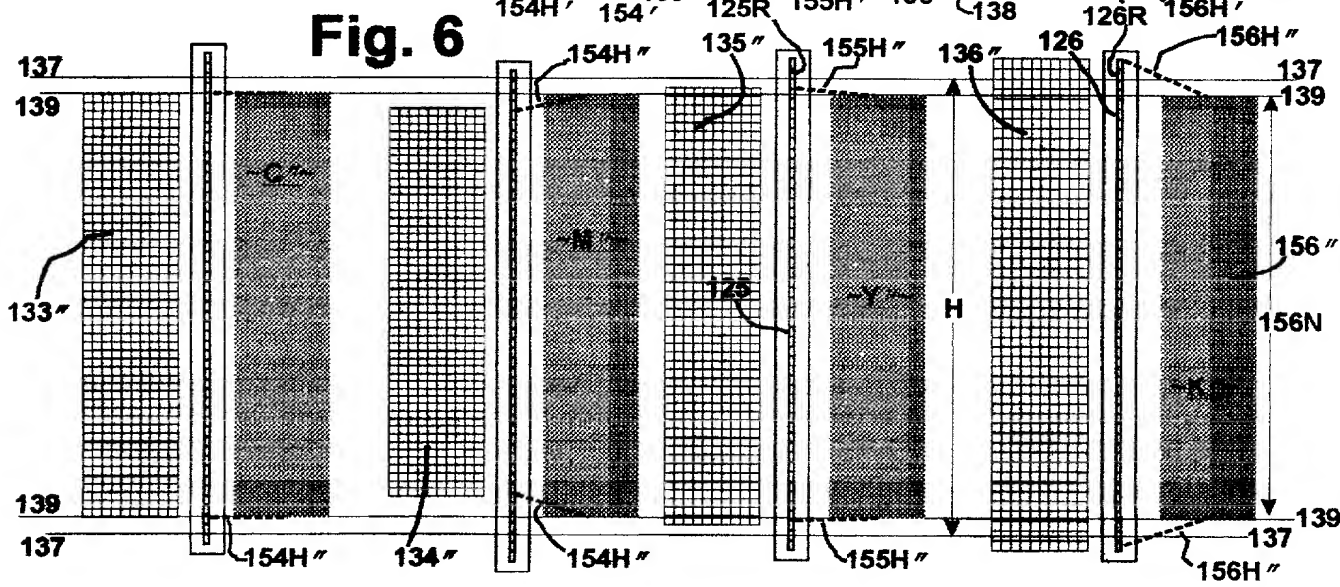


Fig. 6



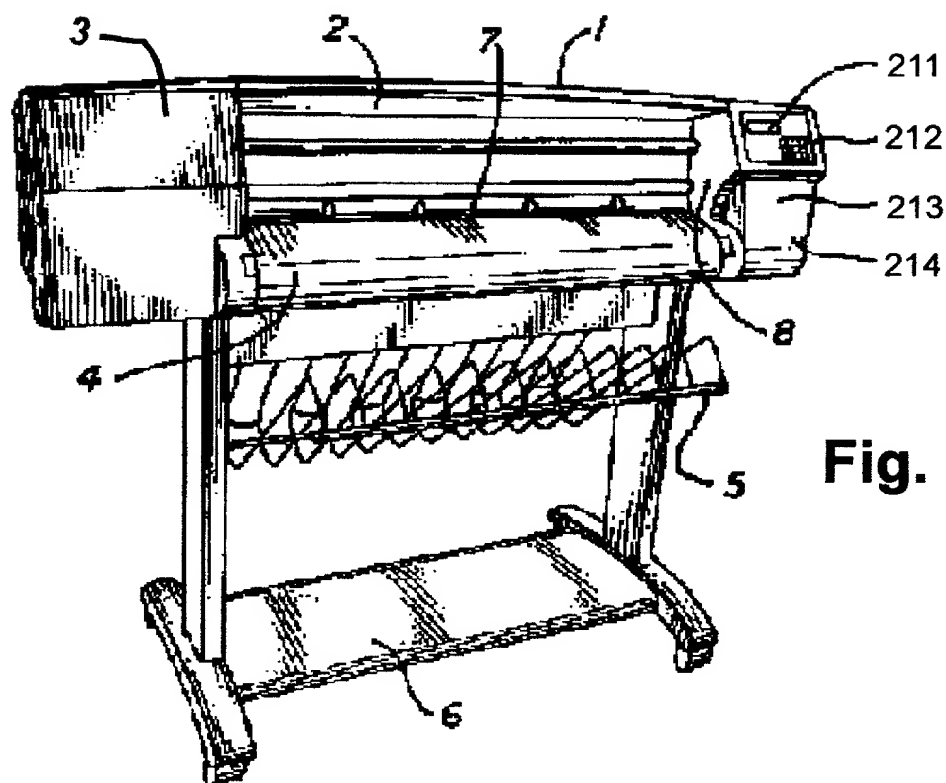


Fig. 7

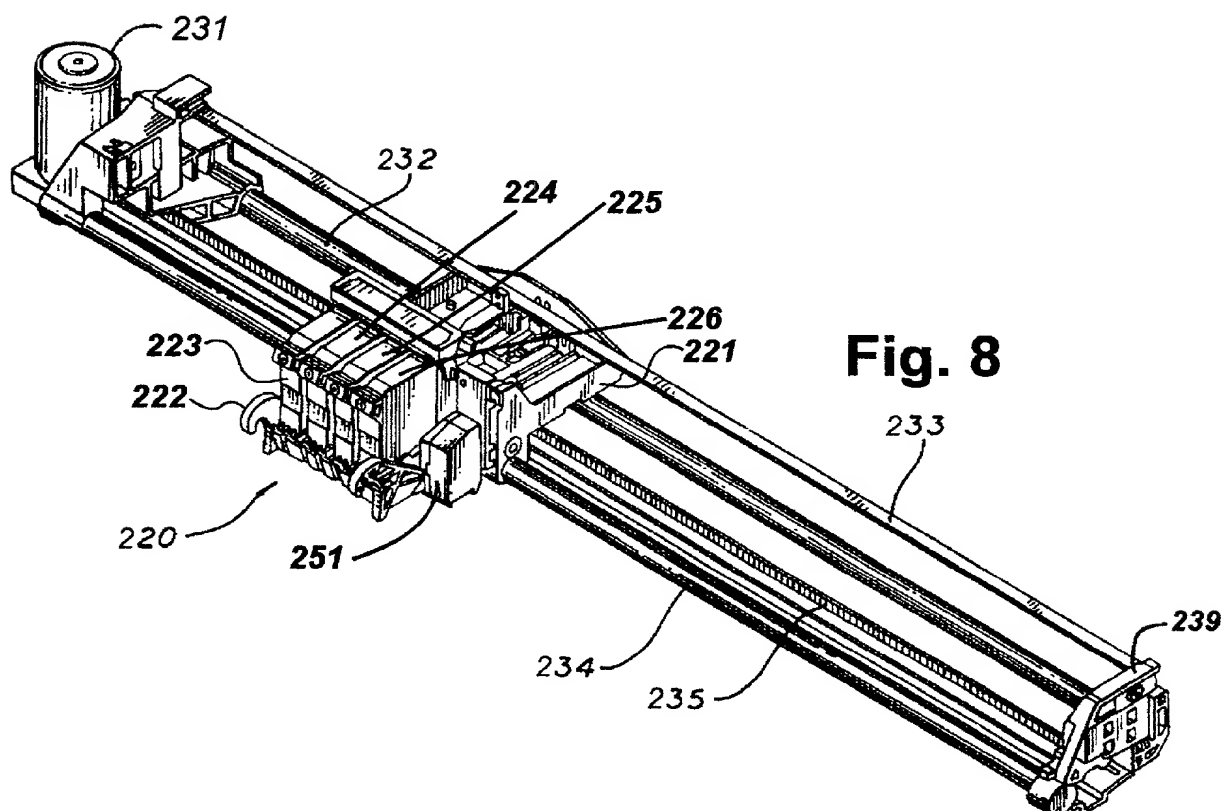
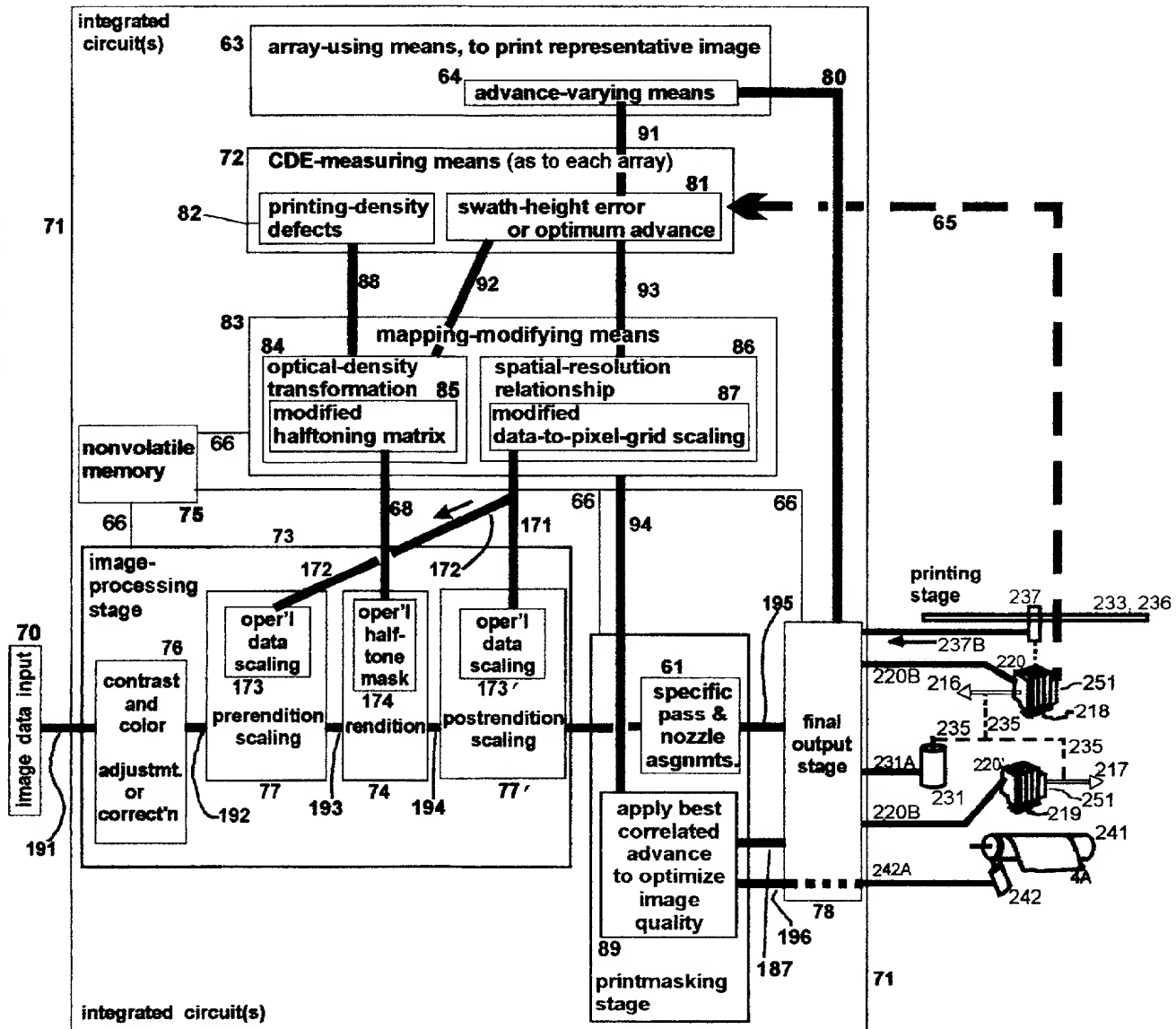


Fig. 8

Fig. 9



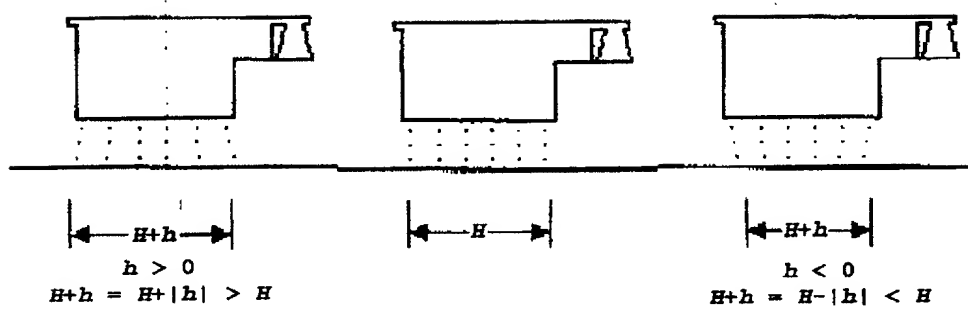


Fig. 10

Fig 11

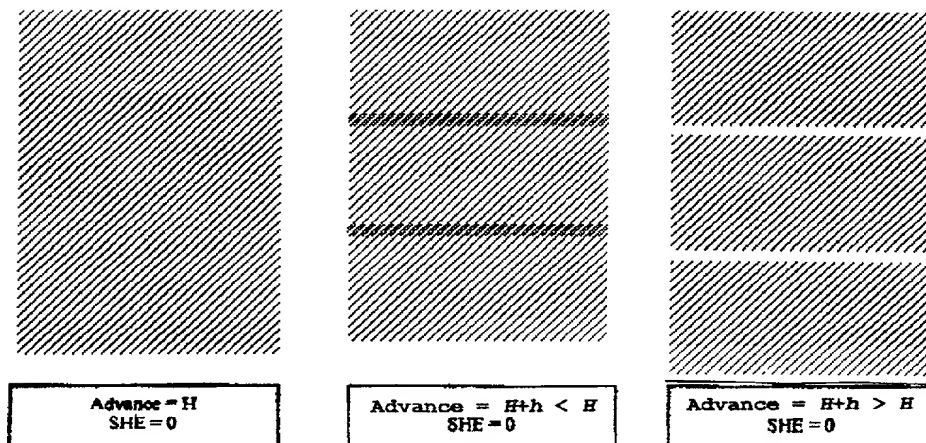
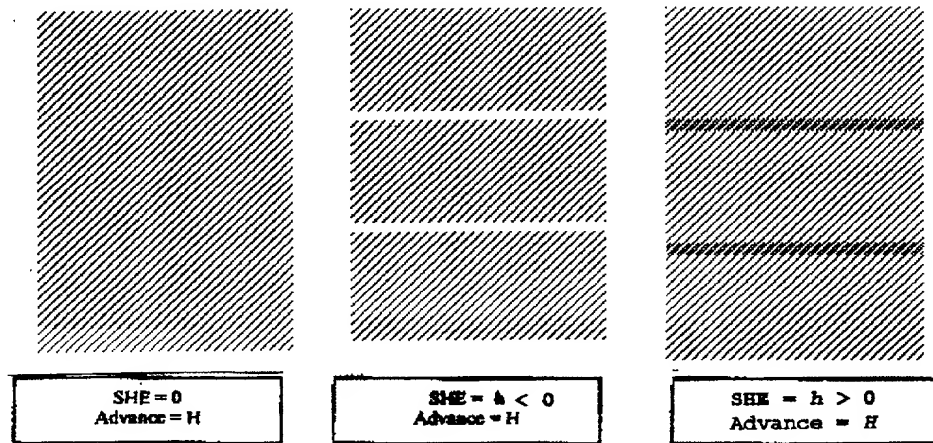


Fig. 12

**DECLARATION AND POWER OF ATTORNEY
FOR PATENT APPLICATION**ATTORNEY DOCKET NO. 60990005-1
(xHPZ-26)

As a below named inventor, I hereby declare that:

My residence/post office address and citizenship are as stated below next to my name;

I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled:

**"APPARATUS AND METHOD FOR MITIGATING
COLORANT-DEPOSITION ERRORS IN INCREMENTAL PRINTING"**

the specification of which

☒ is attached hereto. (Leave blank in response to Notice of Missing Parts)☐ was filed on _____ as Application Serial No. 09/ ,☐ was amended by the preliminary amendment filed with the original application papers.

I hereby state that I have reviewed and understood the contents of the above-identified specification, including the claims, as amended by any amendment(s) referred to above and that I have disclosed the best mode for carrying out the invention as of the effective filing date of this application. I acknowledge the duty to disclose all information which is material to patentability as defined in 37 CFR 1.56. If this is a continuation-in-part application, I acknowledge the duty to disclose all information known to me to be material to patentability as defined in 37 CFR 1.56 which became available between the filing date of the prior (priority) application and the National or PCT international filing date of this continuation-in-part application.

☐ In compliance with this duty there is attached an information disclosure statement 37 CFR 1.97.**Foreign Application(s) and/or Claim of Foreign Priority**

I hereby claim foreign priority benefits under Title 35, United States Code Section 119 of any foreign application(s) for patent or inventor(s) certificate listed below and have also identified below any foreign application for patent or inventor(s) certificate having a filing date before that of the application on which priority is claimed:

COUNTRY	APPLICATION NUMBER	DATE FILED	PRIORITY CLAIMED UNDER 35 U.S.C. 119
- none -	-	-	YES: <input type="checkbox"/> NO: <input type="checkbox"/>
			YES: <input type="checkbox"/> NO: <input type="checkbox"/>
			YES: <input type="checkbox"/> NO: <input type="checkbox"/>

U. S. Priority Claim

I hereby claim the benefit under Title 35, United States Code, Section 120 of any United States application(s) listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States application in the manner provided by the first paragraph of Title 35, United States Code Section 112, I acknowledge the duty to disclose material information as defined in Title 37, Code of Federal Regulations, Section 1.56(a) which occurred between the filing date of the prior application and the national or PCT international filing date of this application:

APPLICATION SERIAL NUMBER	FILING DATE	STATUS (patented/pending/abandoned)
- none -	-	-

POWER OF ATTORNEY:

As a named inventor, I hereby appoint the attorney(s) and/or agent(s) listed below to prosecute this application and transact all business in the Patent and Trademark Office connected therewith.

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818/249-5961

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

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Inventor's Signature _____

October , 2000
Date

**DECLARATION AND POWER OF ATTORNEY
FOR PATENT APPLICATION (continued)**

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Full Name of # 5 joint inventor: _____ Citizenship: _____
Residence/Post Office Address: _____
Inventor's Signature _____ Date _____

Full Name of # 6 joint inventor: _____ Citizenship: _____
Residence/Post Office Address: _____
Inventor's Signature _____ Date _____

Full Name of # 7 joint inventor: _____ Citizenship: _____
Residence/Post Office Address: _____
Inventor's Signature _____ Date _____

Full Name of # 8 joint inventor: _____ Citizenship: _____
Residence/Post Office Address: _____
Inventor's Signature _____ Date _____

(Use Next Page For Additional Inventor(s) Signature(s))